Refinement of the Bottom-side vTEC Scaling Parameter for Correcting Ionospheric Path Delays in Sentinel-1 Data

Christoph Gisinger*[1], Giorgio Gomba[1], Mainul Hoque[1], Antonio Valentino[2], Muriel Pinheiro[3], Guillaume Hajduch[4]

[1]German Aerospace Center (DLR) [2]Starion Italia S.p.A. [3]European Space Agency [4]Collecte Localisation Satellites (CLS)

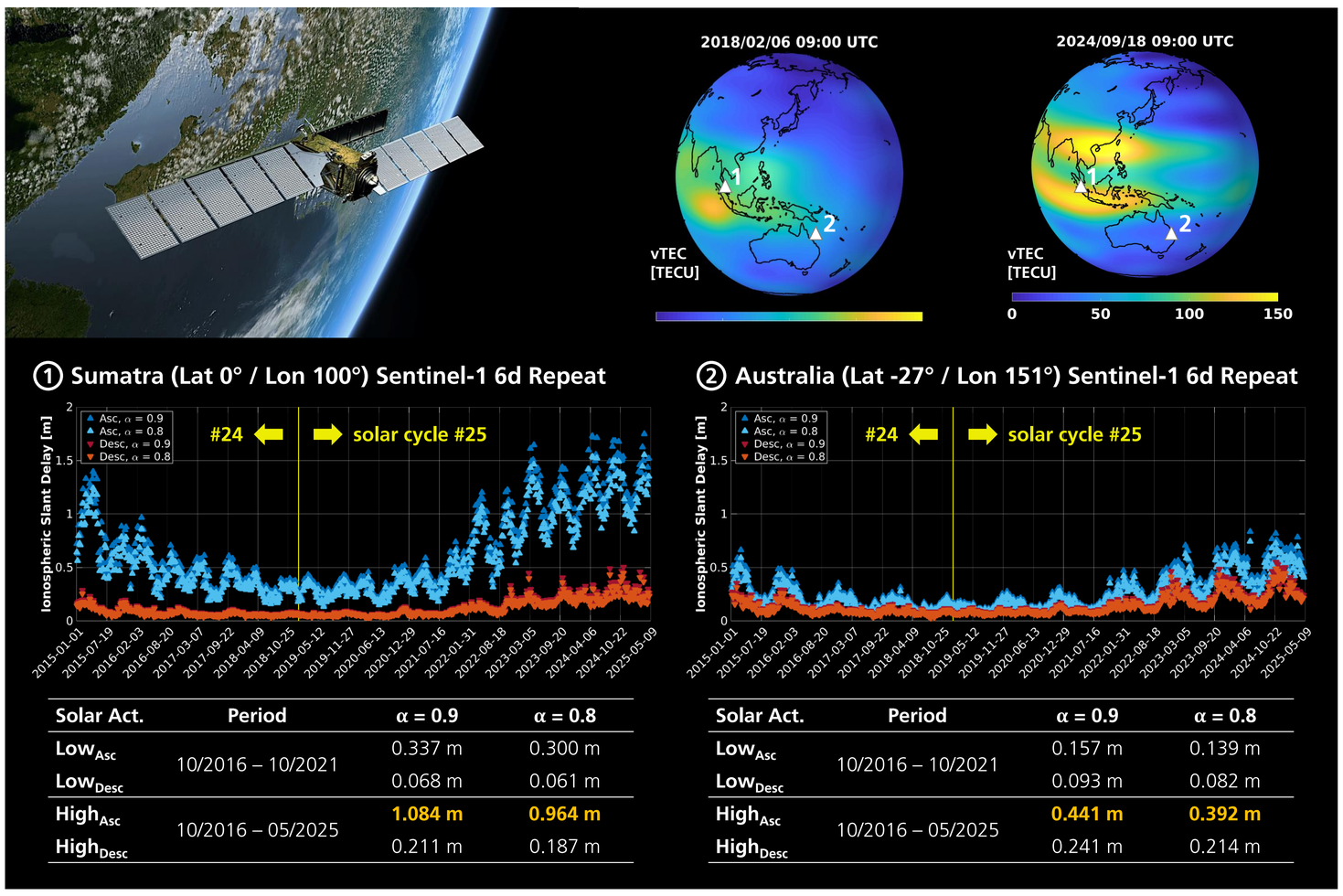
*christoph.gisinger@dlr.de

Ionospheric Delay & Sentinel-1

Driven by the approximately 11-years solar cycle, the **impact of ionosphere dynamics** on **Copernicus Sentinel-1 satellites** spans from **minor degradation of precise orbit solutions** to **meter-level path delays in the C-band SAR** (5.4 Ghz) image data.

SAR Mission Performance Cluster (**SAR-MPC**) routinely **monitors S-1 product quality**. During past years, we noticed **ionosphere-related limitations with** the **S-1 ETAD product** that aims to provide accurate **layers for geometric correction** of S-1 SAR data [1].

A major **source of uncertainty** in the ETAD ionospheric correction layer stems from the **reduction of vertical total electron content (vTEC)** provided by GNSS for the **part below S-1 orbit height**, which can be modelled via a **scaling factor**, see Fig. 1.



Solar Act.	Period	α = 0.9	α = 0.8
Low_{Asc}	10/2016 – 10/2021	0.337 m	0.300 m
Low_{Desc}		0.068 m	0.061 m
$High_{Asc}$	10/2016 – 05/2025	**1.084 m**	**0.964 m**
$High_{Desc}$		0.211 m	0.187 m

Solar Act.	Period	α = 0.9	α = 0.8
Low_{Asc}	10/2016 – 10/2021	0.157 m	0.139 m
Low_{Desc}		0.093 m	0.082 m
$High_{Asc}$	10/2016 – 05/2025	**0.441 m**	**0.392 m**
$High_{Desc}$		0.241 m	0.214 m

Fig. 1 Impact of TEC scaling factor on ionospheric path delay corrections for Sentinel-1. ETAD-type corrections based on CODE TEC maps computed for Sentinel-1 ascending and descending stacks located at Sumatra and Australia, assuming 6 day repeat acquisitions. Differences of up to 10 cm are found in ascending data during high solar activity.

Adjustment of vTEC Scaling Factor from Sentinel-1 IW data

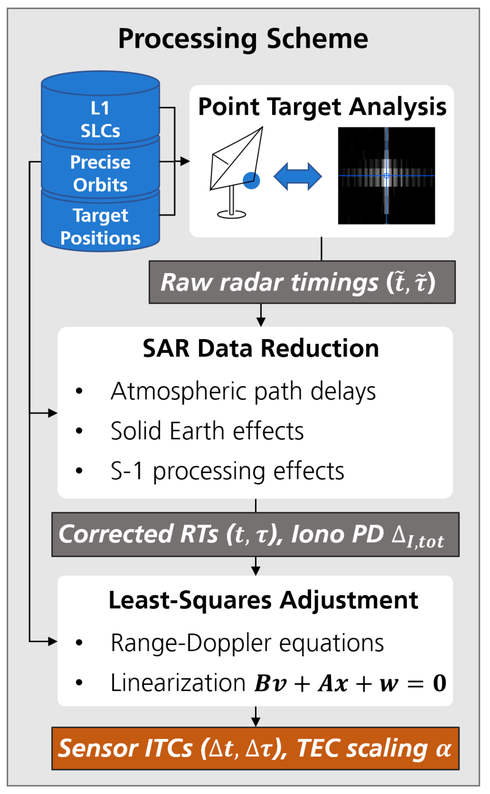
The MPC findings led to an **evaluation of the scaling factor**. Our analysis with the **3-D ionosphere model NEDM2020** showed that **seasonal effects dominate** for **S-1 sun-synchronous orbits** (6h and 18h local passing time), whereas **high solar activity** should only have **minimal impact on the TEC ratio**.

Contrarily, the **long-term residuals of S-1 IW geolocation analysis** of reference targets **indicate ranging errors dominated by high solar activity**, see Fig 2.

From **S-1A/B/C IW data of 11 reference targets spanning 6 sites**, we performed a joint **Least-Squares estimate of the scaling factor** and **sensor timing offsets** [2].

Least-squares results of TEC factor and instrument timing calibration (ITC) from 8.5 years of S-1 IW data.

Sensor	TEC scaling α	Range ITC $\Delta\tau$	Azimuth ITC Δt
S-1A	**0.78 ± 0.004**	0.106 ± 0.001 m	0.043 ± 0.003 m
S-1B		-0.018 ± 0.001 m	-0.218 ± 0.005 m
S-1C		0.344 ± 0.004 m	-0.134 ± 0.022 m



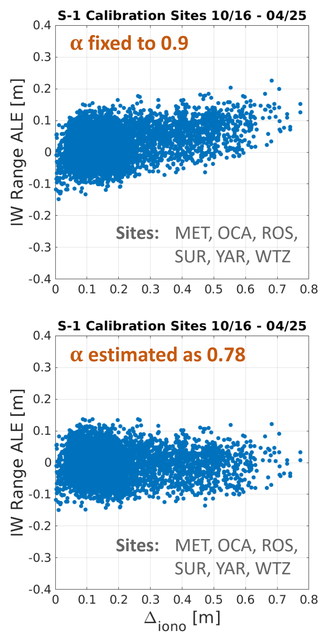


Fig. 2 Range localization error of CR targets versus ionospheric correction for different scaling factors.

Validation Results and Conclusions

Our **comparison results of TEC scaling factors** derived from **spatio-temporal modelling of NEDM2020** and from **SAR data adjustment** show an **advantage for the data driven approach**, see Fig 3.

In conclusion, the TEC scaling factor **configuration for ETAD product generation** was updated **from 0.9 to 0.78** with the **new ETAD processor version 3.0** introduced **in June 2025**.

	Rg ALE $\alpha_{0.90}$	Rg ALE α_{NDEM}	Rg ALE $\alpha_{0.78}$	Az ALE
S1	**0.049 ± 0.060 m**	**0.035 ± 0.059 m**	**0.014 ± 0.061 m**	**0.064 ± 0.277 m**
S1A	0.051 ± 0.062 m	0.036 ± 0.061 m	0.012 ± 0.059 m	0.093 ± 0.286 m
S1B	0.041 ± 0.049 m	0.029 ± 0.047 m	0.021 ± 0.047 m	-0.004 ± 0.234 m
S1C	0.076 ± 0.065 m	0.064 ± 0.069 m	0.004 ± 0.059 m	-0.015 ± 0.277 m

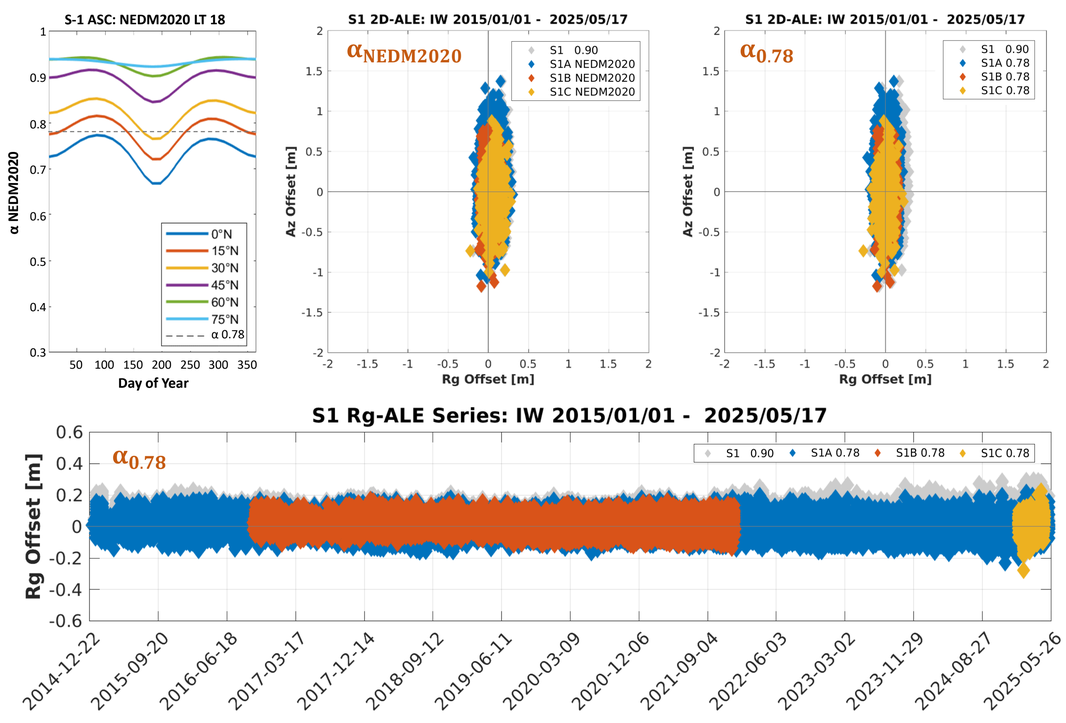


Fig. 3 Validation of TEC scaling factor methods over 8 test sites in Europe, Australia and North America, hosting a total of 84 CRs. Sentinel-1 A/B/C IW data covering 2015 to 2025. Geolocation results of nominal α=0.9 configuration (background) versus dynamic α of NEDM2020 and data driven α=0.78.

References on Copernicus SentiWiki

[1] *Hajduch et al., S-1 Annual Performance Report for 2024, Chapter 5.2 Geometric Validation, SAR-MPC-0715, issue 2.1, 02/04/2025*

[2] *Gisinger et al., Adjustment of vTEC Scaling Factor for S-1 Orbit Altitude, SAR-MPC-0NNN, issue 1.0, 2025 (in preparation)*

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